Modeling of Finite Depth Wind Wave Dissipation

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LONG-TERM GOAL

The long-term goal is to obtain a source function for the spectral wind wave energy dissipation rate due to wave breaking, based on understanding of the physics of the dissipation processes both in deep and finite depth environments. The resulting form must be applicable for use in routine wave prediction models.

SCIENTIFIC OBJECTIVES

The objectives are to establish a description of the “white-capping” dissipation both as a spectral function and a function of environmental conditions. To date, knowledge of the spectral distribution of energy losses due to wave breaking is so poor that scientific debate continues on whether, in the spectral sense, low-frequency dissipation exists or not. Also there is little knowledge of the dependence of the dissipation rate function on wind and wave field characteristics, other hydrodynamic properties and interaction with the bottom. All of these factors make dissipation rate functions used in present day wave models, to a large extent, speculative.

APPROACH

In a series of recent papers (Banner and Tian, 1998; Banner, Babanin, and Young, 2000; Babanin, Young and Banner, 2001; Song and Banner, 2001), the investigators have proposed that whitecap dissipation is a result of the hydrodynamic effects associated with deforming ocean wave groups. Based on these physical considerations, they have been able to describe the probability of breaking as a function of environmental conditions, which include properties of the local wind and wave field, shear current and bottom interaction. The function exhibits phase transition behaviour, with the threshold now well-established on the basis of diverse data, including those obtained during the ONR Lake George Project. The breaking probability dependence is of a general form and applicable both in deep water and in finite water depths.

The next important stage is to recast the probability model into a source term capable of incorporation in a spectral wave prediction model. Investigation in deep water has been very encouraging, and a new dissipation function based on the threshold-like two-phase behaviour of the whitecapping process was suggested, with significant improvement in model performance (Alves and Banner, 2001). An extension of this wave energy dissipation form into fetch-limited finite depth conditions is the aim of this Project, with this newly proposed form to undergo extensive calibration using the depth-limited data set collected at Lake George.

The calibration will require usage of a wave model. Initial tests of the source term formulations will be carried out using the one spatial dimension WTR model of Don Resio, with the four-wave non-linear interaction term modified for finite depth conditions. In the second phase of the Project, the source terms found to be optimal in the one-dimensional model will be incorporated into the two-dimensional SWAN model.

Extensive model testing of the new dissipation function requires an accurate representation of the other source terms. The atmospheric input, triad non-linear, bottom friction and the total dissipation terms are all being evaluated by the investigators as part of the related Lake George Project. The first year priority has been to formulate these source terms for use in the model.

WORK COMPLETED

The wind input study has been completed and two papers are presently being prepared for the Journal of Atmospheric and Oceanic Technology and the Journal of Fluid Mechanics. The wind input has been accurately measured and parameterized in terms of the local wind and wave field properties. Enhancement of the wind input as a function of wave breaking activity was investigated and evaluated.

Estimates of the wave energy dissipation rate in the water column were obtained by means of measurements of the isotropic turbulence spectra at different depths below the surface, as well as estimates of the dissipation in the bottom boundary layer. This allowed verification of the total energy balance. Two presentations on this topic were made at the 8th WISE meeting in Orillia, Canada in April – May, 2001.

A study of free and forced triad interaction terms (joint with Yehuda Agnon of the Technion University, Israel) is currently in progress.

RESULTS

Wind Input

The Lake George Project (progress report ONR N00014-00-1-0012 (CDYoun01)) allowed determination of the input function of the form:

$$I(f) = \frac{\rho_a}{\rho_b} g\gamma(f) f P(f),$$

where $\gamma(f)$ is the growth increment function: $\gamma(f) = a(\frac{U_{\lambda(f)/2}}{c} - 1)^2$.

These formulae can be used directly to calculate the wind input based on the wave spectrum and the local mean wind information, which is usually available.

The coefficient *a,* which equals *0.14* for the Lake George data set, appears not to be a universal constant. For example, the laboratory results of Donelan (1999) yield $a = 0.28$, twice as large as the present data set. This variability, which appears to be related to a dependence of the wind input on the wave breaking activity, has been investigated in detail as a part of this Project.

Fig. 1 (left panel) illustrates the method used to investigate the wind input enhancement due to wave breaking. The sharp-crested waves in the 2nd, 7th and 12th seconds in the top plot were identified as downwind propagating breakers by means of the synchronised video records. These breakers are also detected by the bottom pressure sensor (bottom plot), which was subsequently used to identify breaking events. The middle subplot shows local running average values of the momentum flux from the wind to the waves. There is clear enhancement of the input, associated with the breakers. This demonstrative result was obtained by means of a wavelet analysis, and it was found that using Hilbert transform analysis gives a consistent outcome.

To quantify the overall effect of wave breaking enhancement of the wind input, average values of the momentum fluxes M_{tot} were obtained for a number of Lake George records, together with M_b - the flux into the breaking waves. The duration of the breaking was t_b in a record of total length t_{tot}. The ratio $M = M_b / M_{tot}$ is the relative momentum flux during the breaking events, whose relative duration is $T = t_b / t_{tot}$. If there is no enhancement due to wave breaking, the ratio *M/T* should be 1. As can be seen in Fig.1 (right panel) this ratio is always larger than 1 and has a mean value close to 4. This result reconciles the Lake George field data and Mark Donelan's laboratory wind input rates.

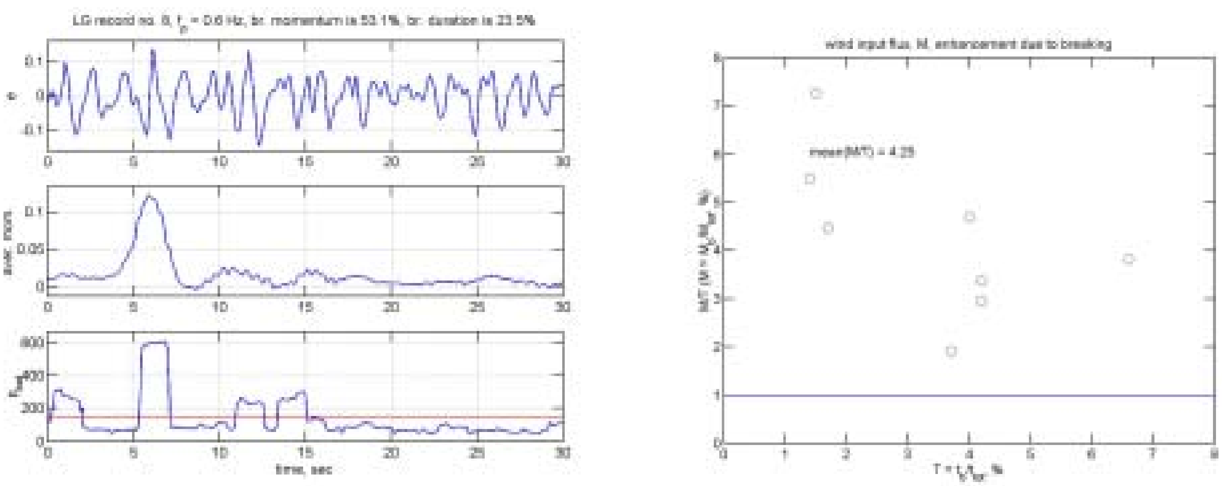


Fig.1. Left: (Top) A 30 second segment of surface elevation record. The sharp-crested waves in the 2nd, 7th and 12th seconds are breakers, propagating downwind. (Bottom) Running average bottom pressure records. Jumps exceeding the threshold level indicate the breaking events. (Middle) Running average (over a dominant wave period) local wind input momentum flux, showing clear enhancement of the momentum flux over the breaking waves. Right: A set of 8 Lake George records, showing the momentum enhancement versus relative duration of the breaking events per record. The enhancement is always larger than unity and is 4 on average.

Whitecapping Dissipation

Estimating the total energy dissipation in the water column is of crucial importance for the present Project and for verification of the total source-sink energy balance. At Lake George, two different devices, the standard SonTek ADV and the Dopbeam (Veron and Melville, 1999), were used to obtain the local dissipation rates by measuring Kolmogorov turbulence spectra. The ADV works only in the frequency domain, whereas the Dopbeam provides both frequency and wavenumber spectra of the velocity fluctuations. In Fig.2 (left panel), frequency spectra of the two are compared. They are in good agreement at the spectral peak which is dominated by wave orbital velocities, but deviate significantly in the high frequency inertial sub-range which is of interest. The wavenumber spectrum, measured by the Dopbeam and converted into the frequency domain is also shown and is consistent with the Dopbeam frequency spectrum. The discrepancies may have important implications for the wave dissipation studies and are presently under scrutiny.

Once the local dissipation rates are obtained at a number of water depths, they need to be integrated over the whole water depth to provide an estimate of the total dissipation per unit of wavy surface. Therefore, knowledge of the depth profile of the dissipation is required, which is impossible to measure precisely using devices such as the ADV or Dopbeam, particularly very close to the surface. The study by Terray et al. (1996) provided a parameterization of the dissipation profile as a z^{-2} function of the water depth *z*. The z^{-2} dependence was confirmed at Lake George (Fig. 2, right panel), however, the parameterization was revised in terms of the dissipation behaviour near the surface and the wind influence on the transition from the linear wall layer to the quadratic function:

$$\varepsilon(z) = \left\{ \begin{array}{lll} const & z \le H_s/3 & \\ z^{-1} & z > H_s/3 & U < 7.5 \\ z^{-2} & z > H_s/3 & U \ge 7.5 \end{array} \right\}$$

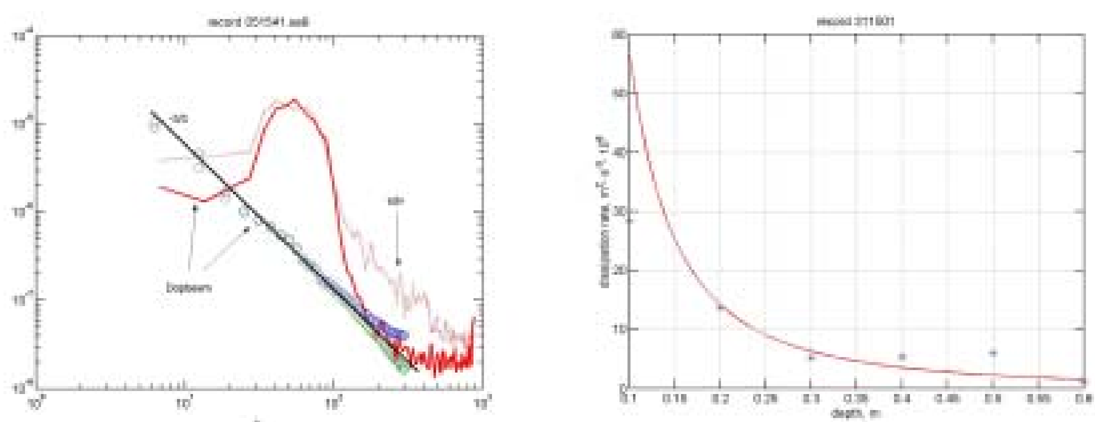
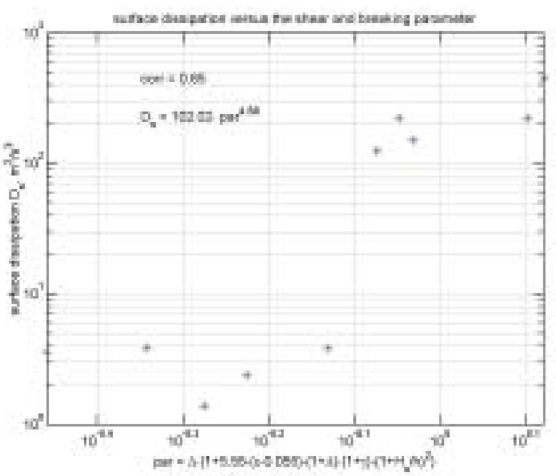


Fig.2. Left. Comparison of Dopbeam (solid line) and ADV frequency spectra. The spectra agree very well at the peak and diverge at higher frequencies, where the ADV level is higher. Also shown is the Kolmogorov level, recalculated from the directly measured wavenumber spectra of the turbulence, which coincides with the Dopbeam frequency spectrum level. Right. ADV measurements at 6 levels below the surface at Lake George show the near-quadratic depth dependence of the dissipation rate.

The above formula, combined with a parameterization of the dissipation rate in the surface layer, provides the starting point for wave modeling studies of the dissipation term. Fig.3 (left panel) shows an attempt at such a parameterization, in terms of the composite breaking parameter proposed by Babanin, Young and Banner (2001).

Bottom Dissipation Rate and Total Source Term Balance

Parameterization of the bottom friction term, the third energy source term to be obtained from the Lake George experiment prior to the numerical modeling phase, was shown in the 2000 ONR Lake George Progress Report and is not repeated here. Fig.3 (right panel) shows the total energy balance for the processed Lake George records, based on knowledge of the wind input and the total dissipation (water column plus bottom). The agreement is very encouraging, given the uncertainties inherent in such a study. It is clear that there is an approximate balance between input and dissipation.



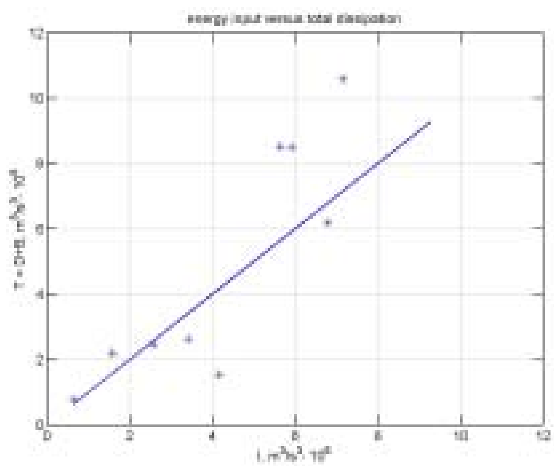


Fig.3. Left. Parameterization of the surface dissipation rate in terms of the composite breaking parameter'par' (Babanin, Young and Banner, 2001). The dissipation rate is a fifth power function of the parameter, with 85% correlation. Right. Verification of the total energy balance. Total (integrated water column plus bottom) dissipation is plotted against total wind input. There is reasonable agreement.

IMPACT/APPLICATION

<u>Wave Modeling.</u> Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water results. The newly proposed terms, particularly the finite depth dissipation function based on physical considerations, will provide a more appropriate representation in such models for the physical processes. As a result, an enhanced ability should result for predicting nearshore wave conditions.

TRANSITIONS

It is expected that the finite depth dissipation function will find a broad spectrum of applications among members of the WISE group and users of SWAN and other shallow water models.

Mark Donelan of the Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida is actively participating in the study of the wind input function and the enhancement of wind input due to wave breaking.

Kendall Melville from the Scripps Institute of Oceanography provided his Dopbeam during AUSWEX and is part of the data processing and investigation team for studies of sub-surface turbulence and total dissipation of wave energy.

Yehuda Agnon from the Technion University, Israel, is using the Project data and results to develop a new triad interaction term for the final version of the model. The purpose of this joint study is to provide a description and parameterization of the three-wave interactions due to not only the resonant non-linear interactions, but also due to the background influence of the wind input and wave breaking.

RELATED PROJECTS

This Project builds upon the successful ONR Lake George Project (N00014-97-1-0234), which is in its final year. The data obtained during the Lake George field experiment, as well as its scientific results, are being extensively used to construct the dissipation function and other source terms in the model under development.

The Project is linked with the ONR CBLAST Project (N00014-00-1-0288, Michael Banner and Lance Leslie are Principal Investigators) on modeling storm spectra. A deep water dissipation function, developed by Michael Banner and his group at The University of New South Wales, Australia, is based on the same physical consideration as the one being developed here.

The Project is coordinated with the SHOWEX Project, sponsored by ONR. Results and data of SHOWEX will be used for verification the modeled dissipation function.

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